

Measurement of Wire Sag in a Vibrating Wire Setup*

Animesh Jain, Ping He, George Ganetis
Superconducting Magnet Division

Brookhaven National Laboratory, Upton, NY 11973

and

Alexander Temnykh
Cornell University

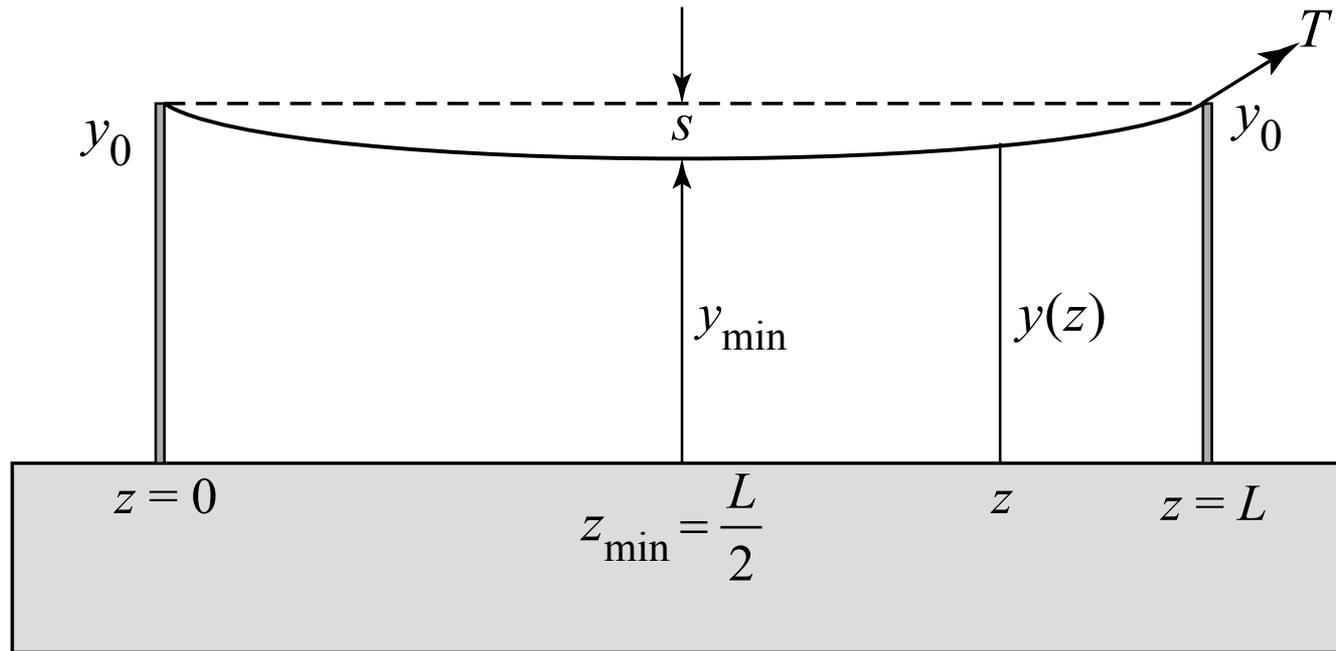
15th International Magnet Measurement Workshop, Fermilab, August 21-24, 2007

* Work supported by the U.S. Department of Energy under contract DE-AC02-98CH10886.

Introduction

- NSLS-II requires a very tight tolerance on the relative alignment of quadrupoles and sextupoles on a girder, which is ~ 6 m long.
- Although individual magnets could be fiducialized using a variety of techniques, one is ultimately limited by the survey accuracy (50-100 μm) for the final installation.
- Based on the accuracy required, and the overall length of the girders, the vibrating wire technique developed at Cornell was chosen for aligning magnets to each other.
- Cu-Be wire sags 500-600 μm for ~ 6 m length. So, accurate calculation of the sag correction is essential.
- How well does the sag formula work?

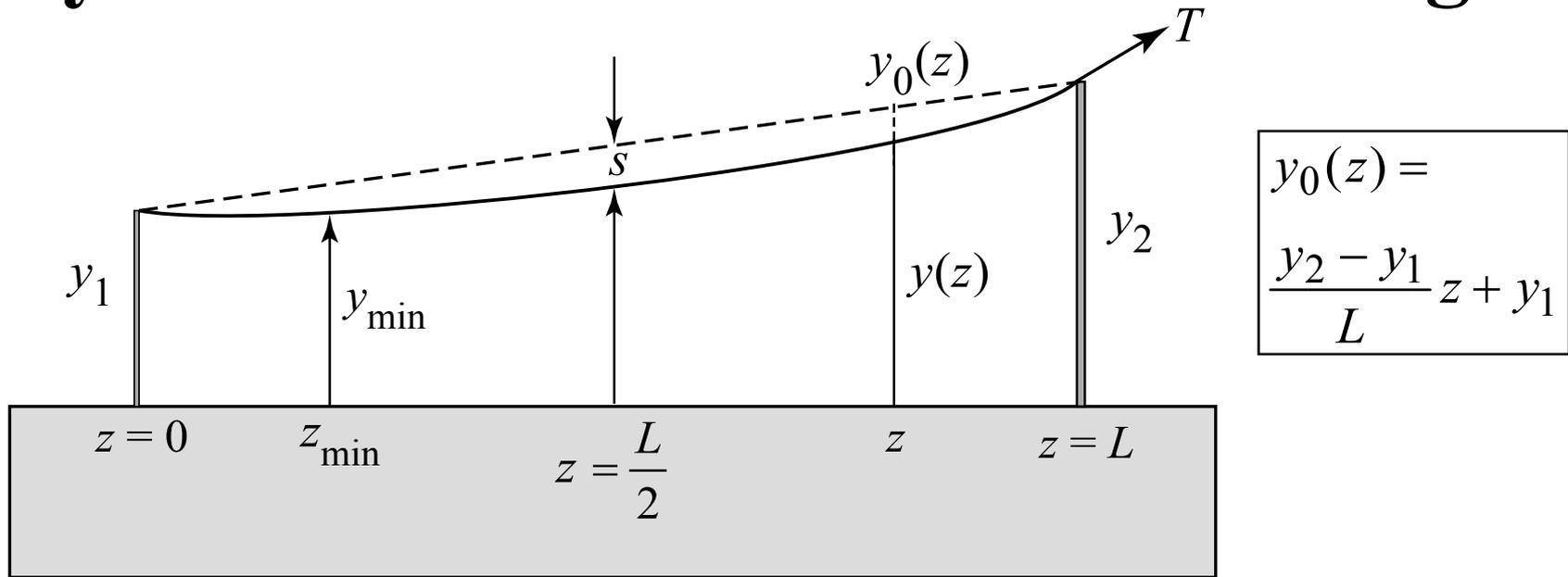
Wire Sag: Symmetric Case



$$y(z) = \left(\frac{m_\ell g}{2T} \right) z(z - L) + y_0 \quad z_{\min} = \frac{L}{2} \quad f_1 = \left(\frac{1}{2L} \right) \sqrt{\frac{T}{m_\ell}}$$

$$\text{Sag} = s = (y_0 - y_{\min}) = \left(\frac{m_\ell g L^2}{8T} \right) = \frac{g}{32 f_1^2}$$

Asymmetric Case: How to Define Sag?



$$y(z) = \left(\frac{m_l g}{2T} \right) z(z - L) + \frac{y_2 - y_1}{L} z + y_1$$

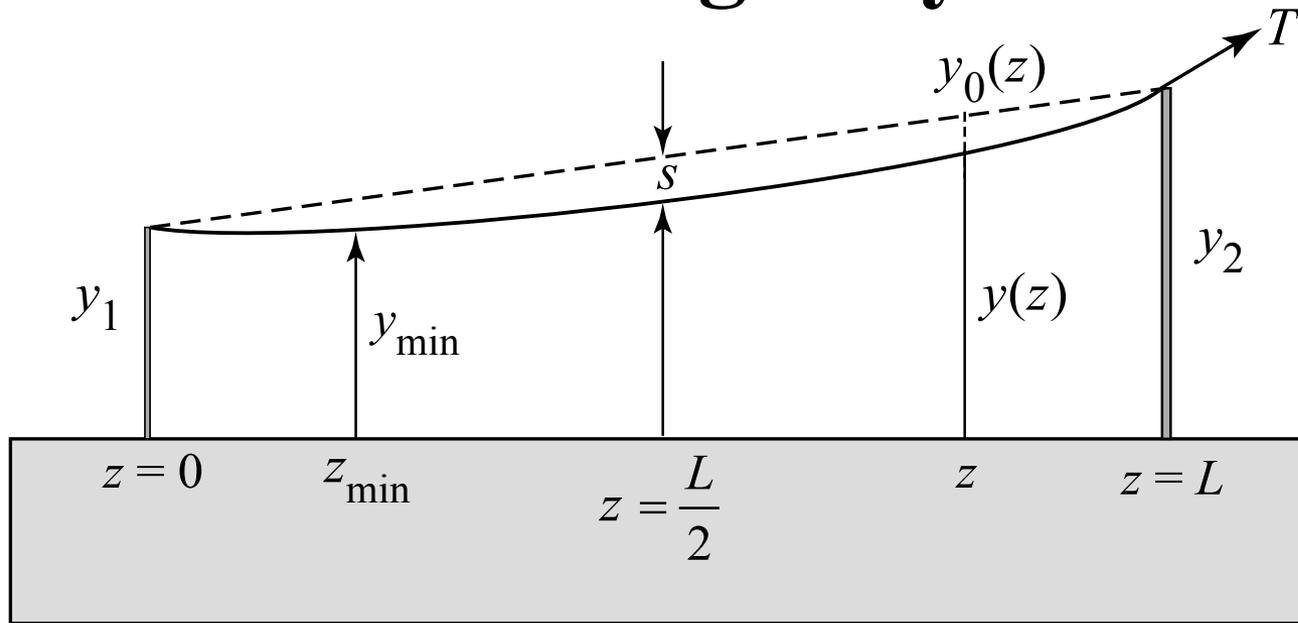
$$z_{\min} = \frac{L}{2} \left[1 - \frac{8(y_2 - y_1)f_1^2}{g} \right]$$

If we define “sag” as departure from straight line at $z = z_{\min}$, then it is given by:

$$y_0(z_{\min}) - y_{\min} = \frac{g}{32f_1^2} - \frac{2f_1^2(y_2 - y_1)^2}{g}$$

Note that z_{\min} may be outside the wire!
 For $y_2 - y_1 = 0.25$ mm, $L = 6$ m, $f_1 = 22$ Hz:
 z_{\min} differs from $L/2$ by ~ 30 cm
 Correction term in “sag” is ~ 6 μ m

Definition of Sag: Asymmetric Case



$$y_0(z) = \frac{y_2 - y_1}{L} z + y_1$$

$$y_0(z) - y(z) = \left(\frac{m_l g}{2T} \right) z(z - L)$$

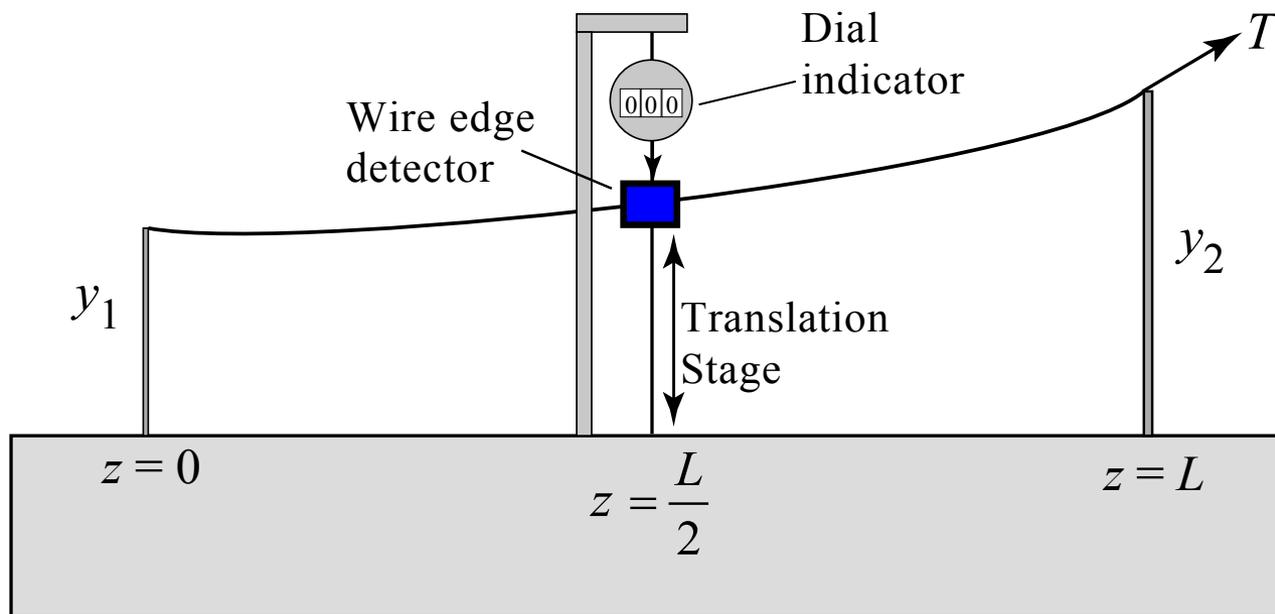
Deviation from straight line at any position.
This has the same form as the symmetric case.

If we define “sag” as the maximum departure from a straight line then:

$$\text{Sag} = s = [y_0(z) - y(z)]_{\max} = \left(\frac{m_l g L^2}{8T} \right) = \frac{g}{32 f_1^2}$$

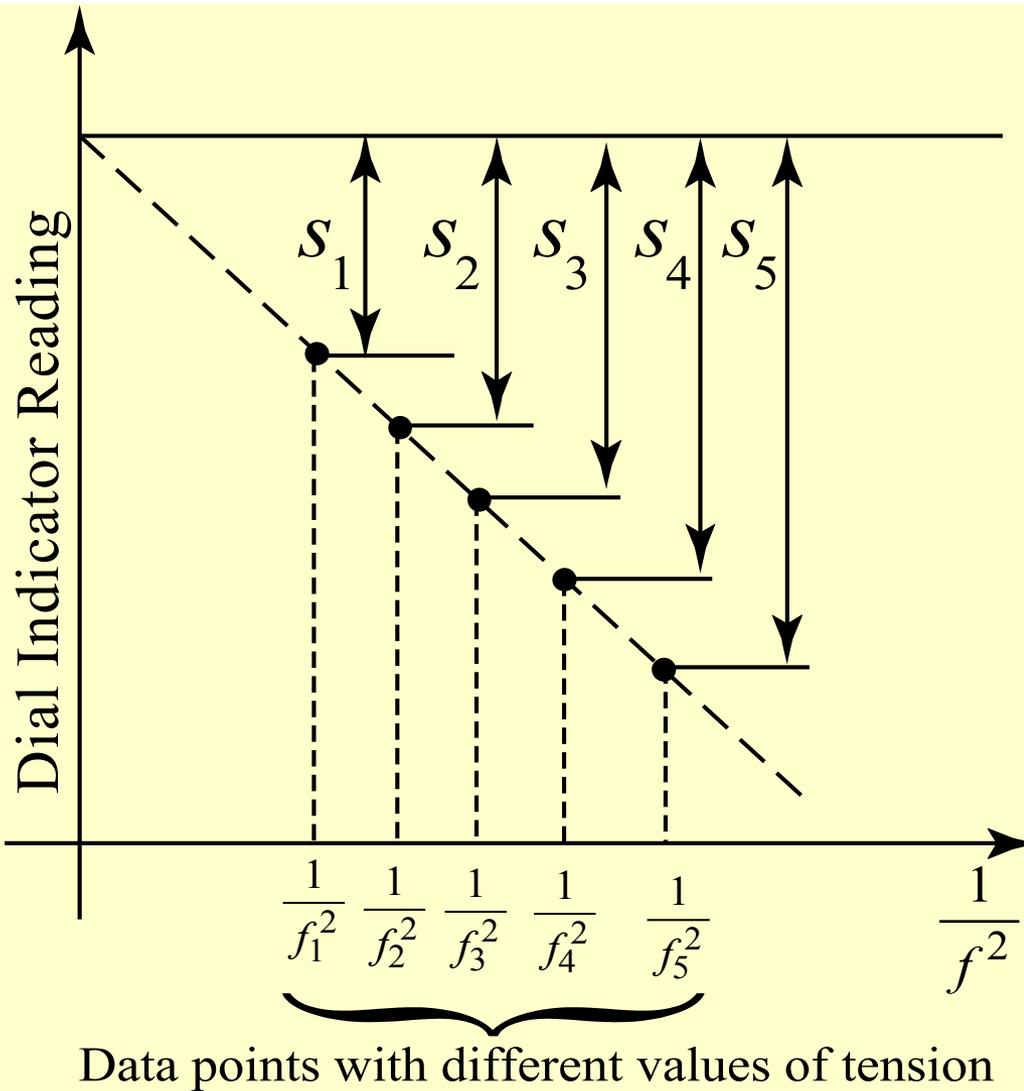
Same as the symmetric case
Maximum departure from straight line always occurs at the midpoint.

Measurement of Sag: Concept



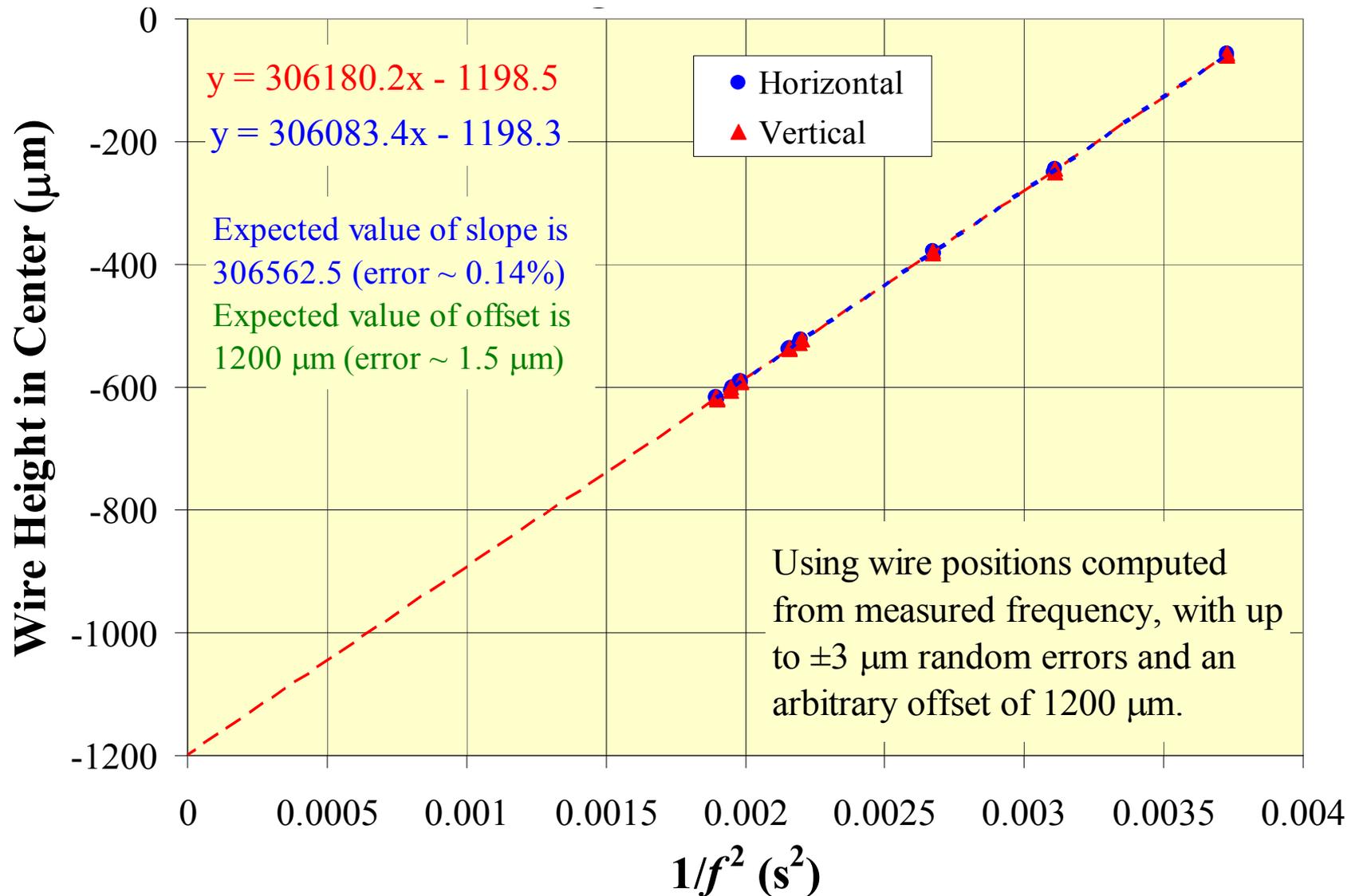
- Set up a wire position detector mounted on a translation stage at the mid point.
- For a given tension, adjust position of detector until null output is obtained.
- Change the tension, and adjust detector again. Measure the amount moved using digital dial indicators.
- Study as a function of tension (or resonant frequency) and compare to theory.

Measurement of Sag: Analysis Concept

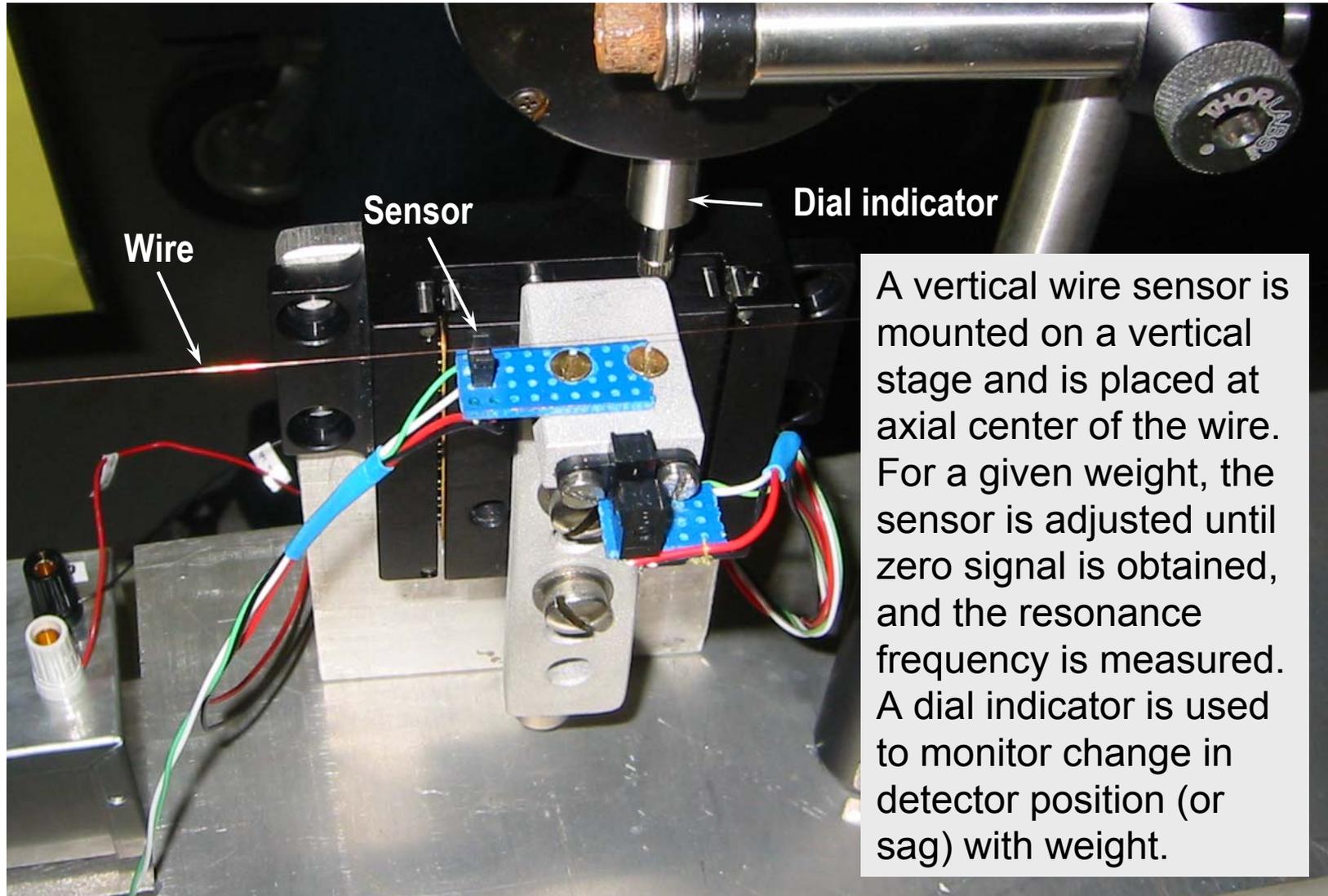


- Vary tension and measure the resonant frequency and the change in wire height.
- Plot dial indicator reading vs. $1/f^2$, which should give a straight line.
- Extrapolate to infinite tension. The difference between the intercept and any given dial reading gives the absolute value of sag for that tension (or frequency).
- Compare to formula.

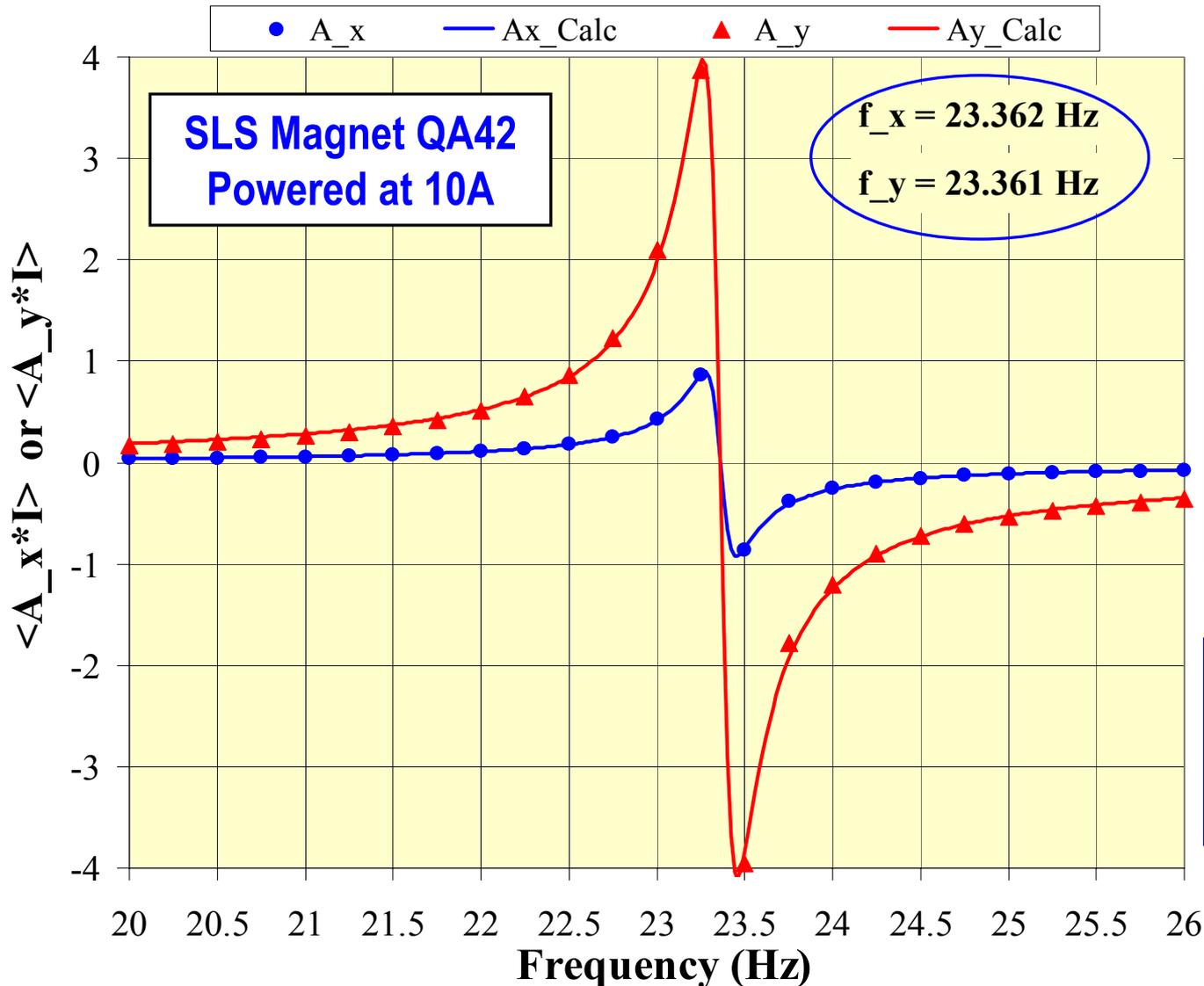
Wire Sag: Simulation with Random Errors



Experimental Setup for Sag Measurements



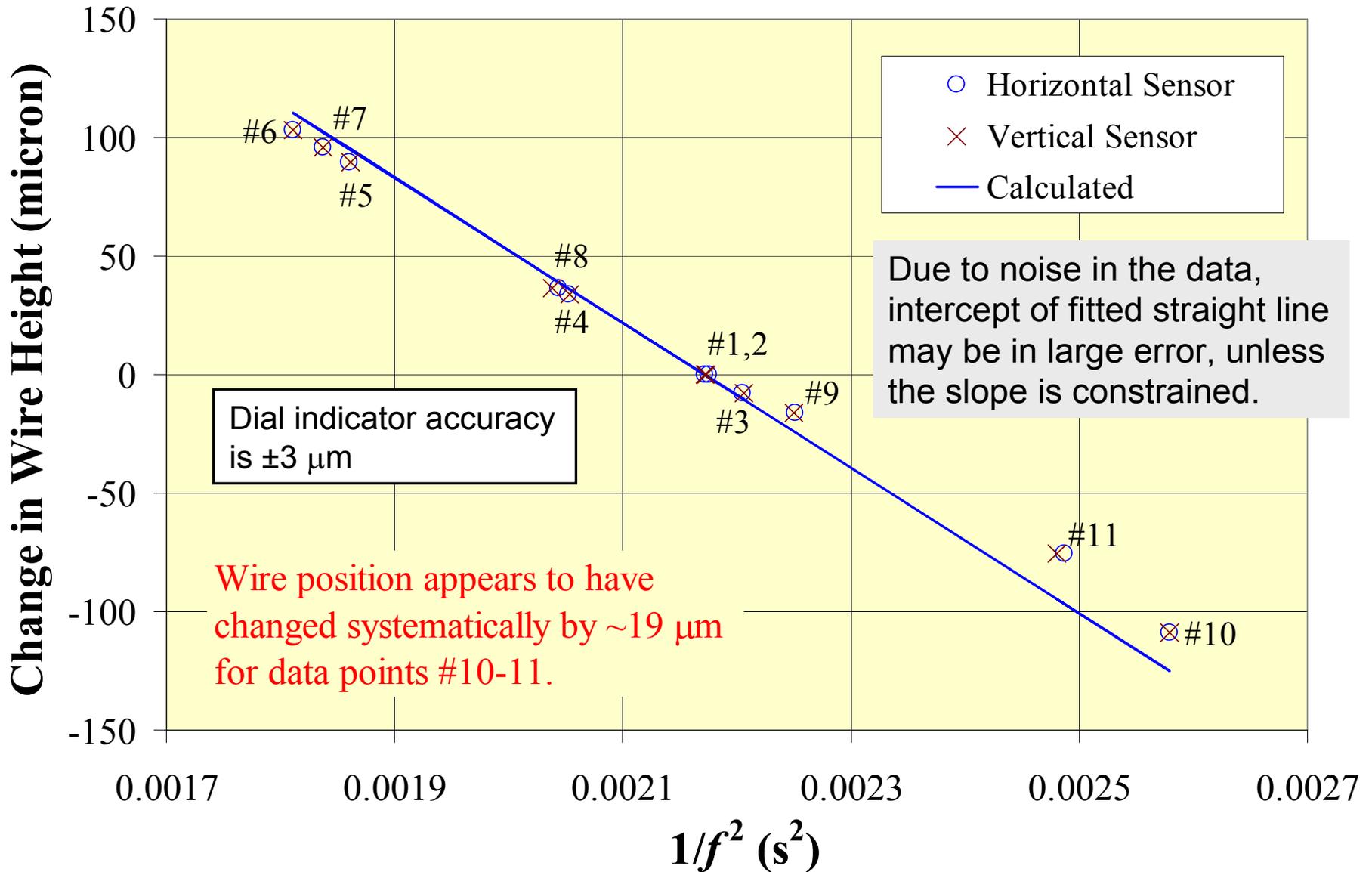
Accuracy of Resonant Frequency



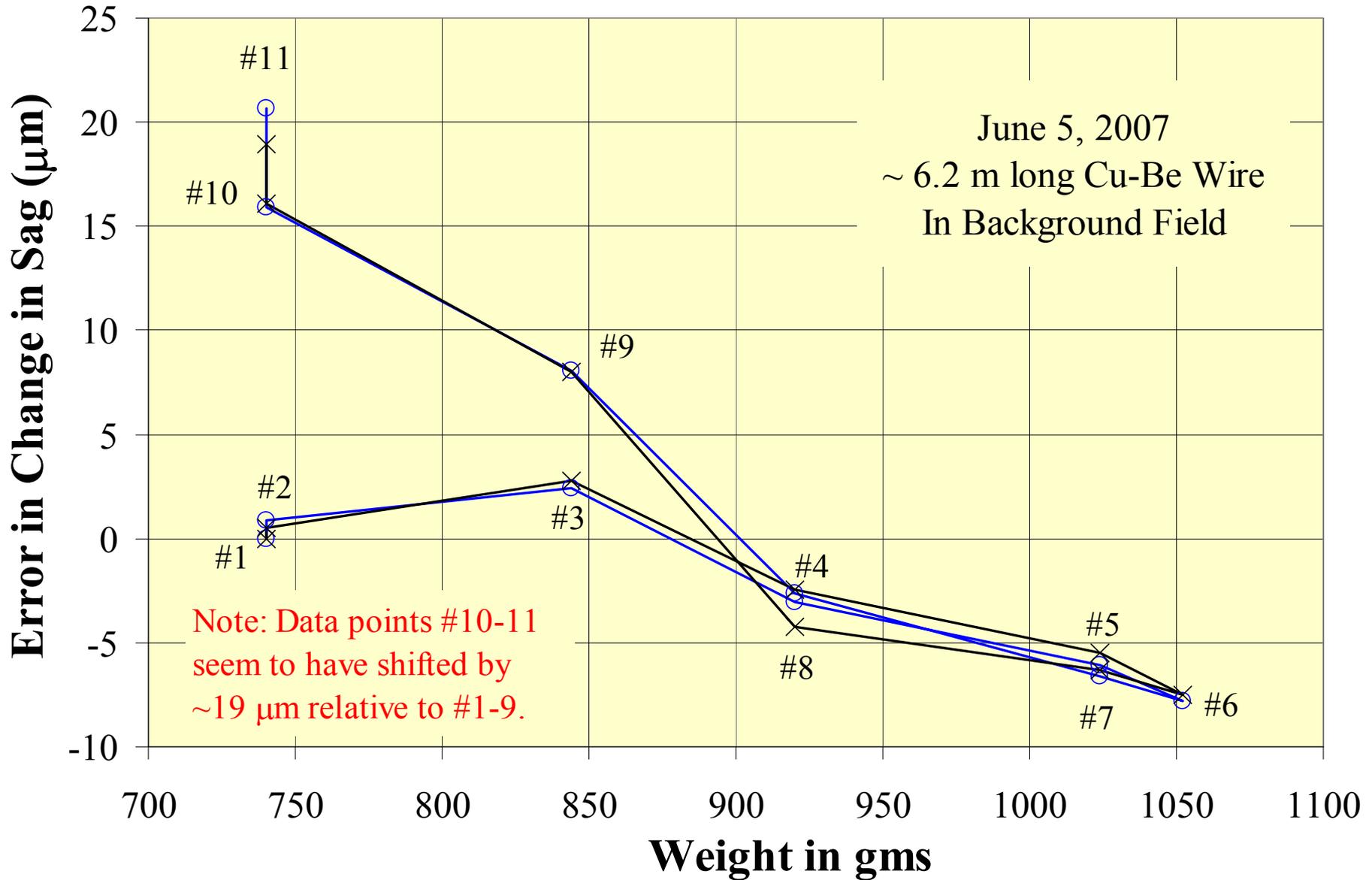
Correction for large wire sag (500 to 600 microns for ~6.2 m length) is very important, which in turn requires a very precise knowledge of resonant frequency.

$$Sag = \frac{g}{32 f^2}$$

Sag: Measured Vs. Calculated



Error in Change of Sag Vs. Weight Used



Summary

- Accurate estimation of sag is critical for precise alignment of multipoles on a girder for NSLS-II.
- A simple set up was used to measure changes in sag as a function of applied tension.
- Noise in the data due to dial indicator resolution, detector noise, wire vibrations, etc. was up to $\pm 5 \mu\text{m}$ in wire height.
- An unconstrained fit to the data gives large uncertainty in the intercept, or the absolute value of the sag. The change from one tension to another, however, generally agreed with theory.
- The set up was not very robust mechanically and unexpected changes in wire position were sometimes seen.
- The experiment will be repeated with a better set up when the R&D vibrating wire system at BNL will be operational.